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The stratigraphy of the Willwood Formation in the vicinity of Sheep Mountain, southwestern Big Horn County, Wyoming

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THE STRATIGRAPHY OF THE WILLWOOD FORMATION IN THE
VICINITY OF SHEEP MOUNTAIN, SOUTHWESTERN
BIG HORN COUNTY, WYOMING

by

John West Neasham

A Thesis Submitted to the
Graduate Faculty in Partial Fulfillment of
The Requirements for the Degree of
MASTER OF SCIENCE

Major Subject: Geology

Approved:

Signatures have been redacted for privacy

Iowa State University
of Science and Technology
Ames, Iowa

1967

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INTRODUCTION

General Statement

This report presents the results of a study of the stratigraphy and lithology of the red-banded, Early Eocene, Willwood Formation in the Big Horn Basin, Wyoming.

Investigations of the Willwood and other red-banded early Cenozoic sediments in the Cordilleran region of the western United States date back more than a century. Abundant mammalian fossil content usually associated with these sediments motivated a large portion of the geologic study, but in recent years the nature of the sediments themselves has also received considerable attention. Knowledge gained has provided a better understanding of the depositional environment of the Willwood Formation and other red-banded strata found throughout the geologic column.

In the present study the writer has focused major attention on the following aspects of the Willwood Formation:

1. The lithology and stratigraphic relationships of the strata exposed in the area of study.
2. The existence of "marker beds" for possible use in local correlation of strata, improved stratigraphic documentation of fossils, and subdivision of the Formation into smaller rock-stratigraphic units.
3. The depositional history of the Willwood.

Physiography and Location of the Area of Study

The Big Horn Basin is located in the northwestern portion of Wyoming and is part of the Middle Rocky Mountain physiographic province (Fenneman, 1931). It extends into south-central Montana and joins with the Missouri Plateau and Great Plains physiographic province. Structurally, the Big Horn Basin represents an elliptical depression surrounded by mountain ranges of the Middle Rockies (see fig. 1). The structural axis trends approximately northwest-southeast and generally parallels the present basin margins. The surrounding mountains, with the exception of the volcanic Absaroka Range, are Laramide orogenic uplifts consisting primarily of exposed Precambrian cores flanked by upturned Paleozoic and Mesozoic strata. Concomitant uplift and subsidence has produced a present-day elevation difference between the Precambrian basin floor and mountain cores of 22,000 feet. A veneer of approximately 17,000 feet of sediment ranging in age from Cambrian to Pleistocene is present in the central portion of the basin. The present relief of the area is the result of erosion and removal of basin sediments and the exhumation of surrounding mountain ranges. This activity has been caused by late Tertiary and Quaternary regional uplift. The basin is essentially in the first cycle of erosion (Mackin, 1947).

Fig. 1. Map of the Big Horn Basin showing surrounding mountain ranges and area of Willwood exposure.

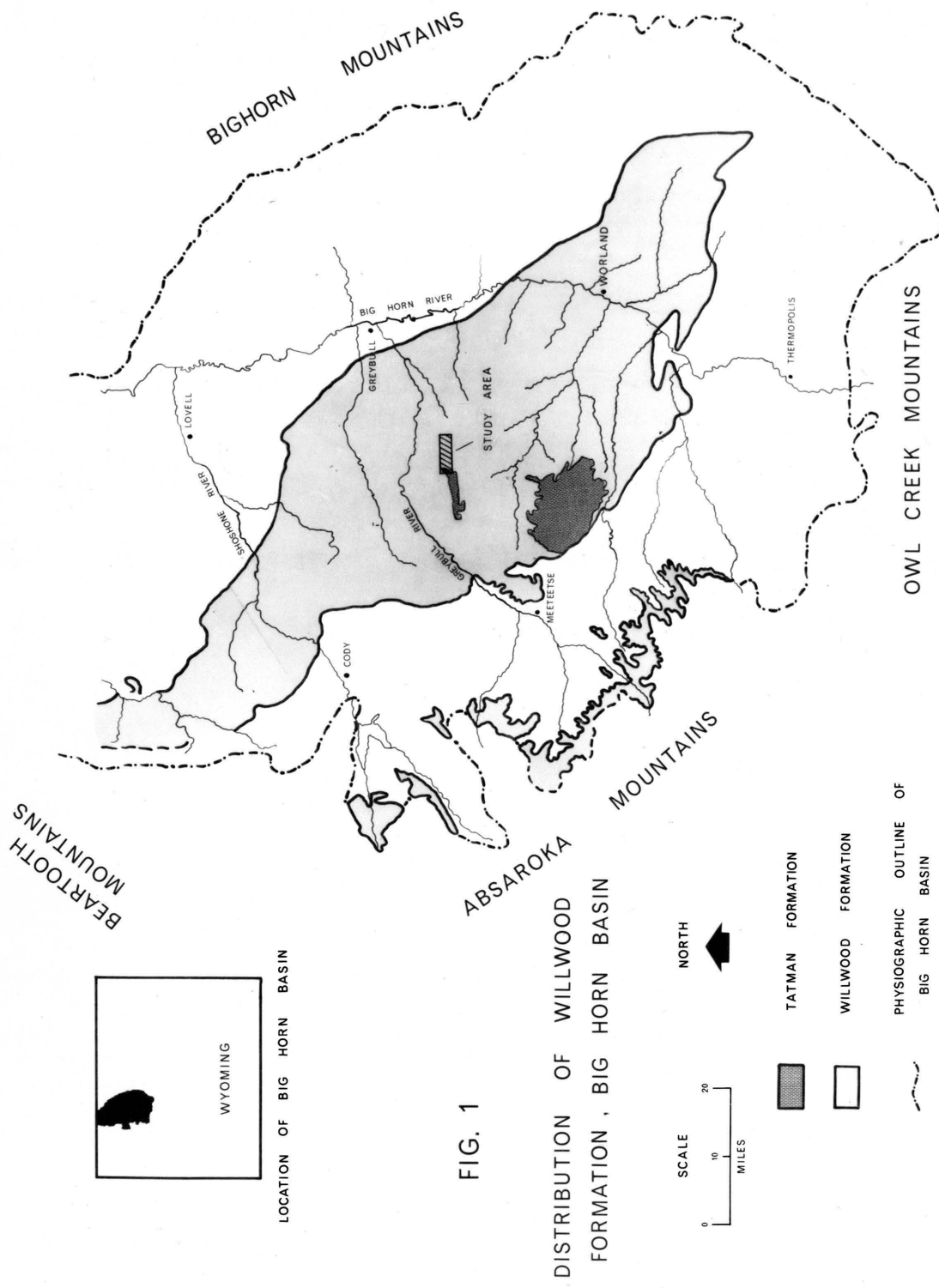


FIG. 1

DISTRIBUTION OF WILLWOOD FORMATION, BIG HORN BASIN

BASED ON VAN HOUTEN (1944)

The topography of the Big Horn Basin displays a variety of landforms. Rugged badlands and broad flat-topped benches dominate the central portion and rise above a generally flat, land surface and broad stream valleys. The badlands are the result of dissection of Cenozoic deposits by past and present drainage systems. Extensive badlands are developed in the McCulloch Peaks area, located some 12 miles northeast of Cody, Wyoming, and in a broad area extending south and southeast from the Greybull River to the vicinity of Worland, Wyoming. Tatman Mountain, situated immediately west of the area of study, and Polecat Bench, located approximately 40 miles northeast of Cody, Wyoming, are the most prominent of the flat-topped benches. They represent remnants of pre-existing basin surfaces cut during the present cycle of erosion.

Encircling this central basin area is a border area 10 to 20 miles wide in which strata deeply buried in the central portion are exposed in a series of northwest-southeast trending folds. Erosion of these folds has produced numerous hogbacks and cuestas - the principal landforms in this border belt area. An erosional escarpment occurs along the western border where the Absaroka Range encounters the basin surface. The marginal belt of folding is partially buried by volcanics in this area.

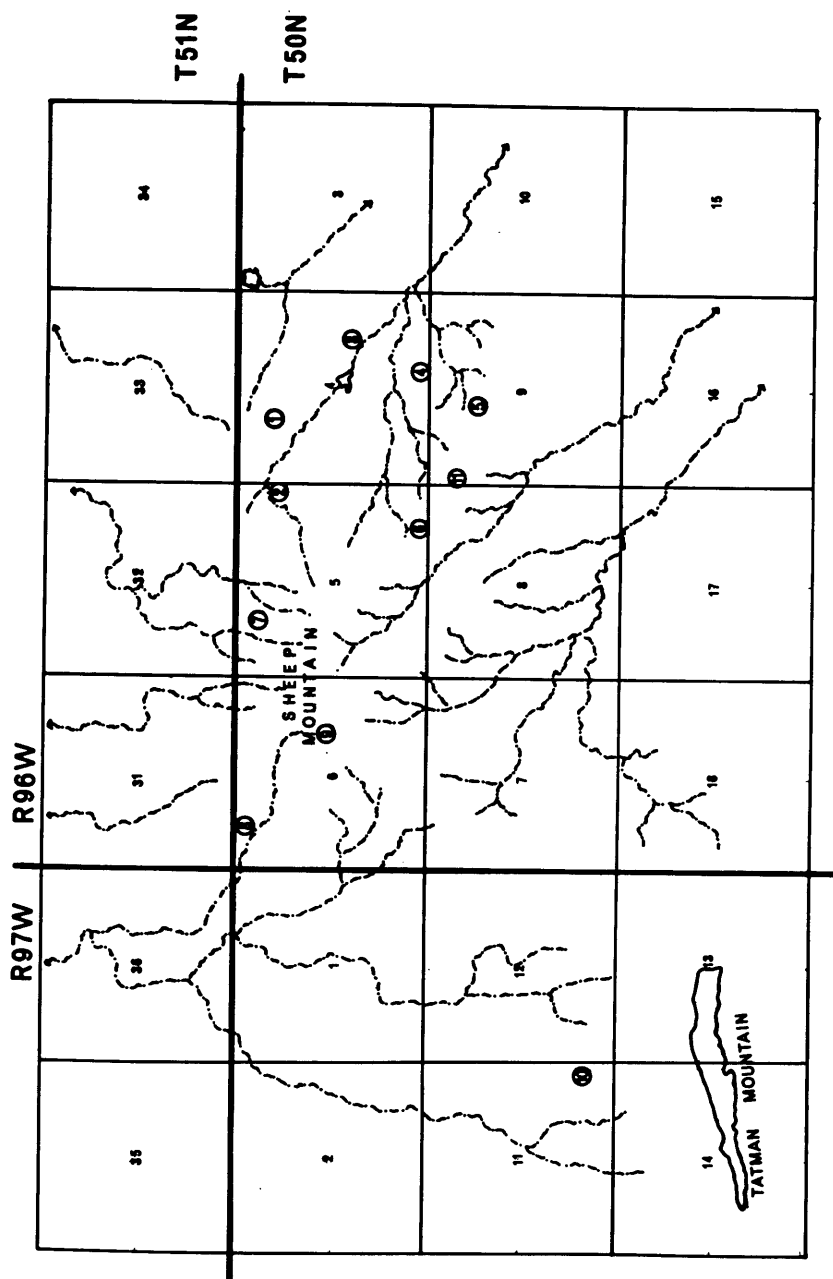
The drainage system of the Big Horn Basin consists primarily of the Big Horn River, traversing the basin from south to north, and its major tributaries, the Greybull and

Shoshoni Rivers, which flow eastward from the Absarokas. The predominance of basin drainage from the west is due to both the greater area drained and the rain shadow cast by the Absarokas over the western slopes of the Bighorn Mountains (Van Houten, 1944). Two processes have characterized the development of the basin drainage pattern; superposition upon Laramide structures as streams have eroded through Tertiary, basin sediments, and stream capture (Mackin, 1947).

An arid climate (less than 10 inches rainfall annually) throughout most of the Big Horn Basin supports a desert brush vegetation of primarily saltbrush, sagebrush, greasewood, and small growths of wheatgrass and needlegrass (Kuchler, 1964). Only along streams are trees such as cottonwoods or willows able to grow.

The present study of the Willwood Formation was conducted in the southwestern portion of Big Horn County approximately 20 miles southwest of Greybull, Wyoming. This area is situated on the northern edge of Willwood badlands extending between the Greybull River and Worland. Although a much larger area of Willwood strata was reconnoitered, detailed study was concentrated in the northwest portion of township 50 north, range 96 west (see fig. 2). This area is dominated by Sheep Mountain, a major topographic high rising approximately a 1000 feet above the basin surface and consisting entirely of Willwood strata. The area was selected for detailed study because of the accessibility, excellence, and completeness of Willwood exposures.

Fig. 2. Index map of the study area showing location of measured sections.



NORTH

FIG. 2 STUDY AREA

MAJOR INTERMITTENT STREAMS
 LOCATION AND NUMERICAL DESIGNATION OF STRATIGRAPHIC SECTIONS

A fine-textured drainage pattern is present in the area, and the erosion by intermittent streams has formed a series of steep-sided, V-shaped valleys and narrow ridges radiating from Sheep Mountain. These provide outcrops suitable for the measurement and bed by bed correlation of Willwood strata.

Method of Investigation

During the summer of 1965 three months were spent studying the stratigraphy and lithology of the Willwood Formation. The major portion of the field work consisted of measurement, detailed description, and sampling of exposures in the study area. Criteria used in the selection of individual exposures included both the amount of stratigraphic interval exposed and the presence of a rock unit which could be traced to a previously measured section. The essentially flat-lying Willwood strata were measured with a tape and hand level. Rock samples were collected in the field to provide for a more complete description and aid in the interpretation of the depositional history of the Willwood. Two measured exposures were "spot sampled" at each change in lithology. Other exposures were sampled only at major lithologic changes.

Laboratory studies of the Willwood samples consisted primarily of thin-section and X-ray analyses. Fifty thin-sections were prepared and examined for mineralogical content and textural properties. Fine-grained rocks not readily

observable with standard petrographic methods were reduced to a fine powder and analyzed on an X-ray diffractometer. Mechanical analyses of a few Willwood sandstones was also performed in an attempt to determine characteristic grain and sorting parameters.

Since the study was concerned with the lithologic and stratigraphic nature of the Willwood Formation, little attention was directed towards the paleontological aspects of the red-banded strata. Fossils encountered in the course of section measurement were noted in the description of rock units. Their general occurrence and identification, however, were not incorporated as part of this study.

PREVIOUS WORK

The existence of red-banded, early Cenozoic deposits in the Big Horn Basin of Wyoming was recorded for the first time by T. B. Comstock, who served as geologist of a reconnaissance party for the Union Pacific Railroad. In 1873 he published a geological description of western Wyoming and supposed the red-banded strata to be Miocene lake beds.

The discovery of mammalian fossils in the Early Tertiary strata of the basin prompted Cope, in 1881, to send out a fossil-collecting expedition. Under the leadership of J. L. Wortman an extensive collection was made, and the first detailed work on the geology of the exposures was accomplished. Cope (1882) published a description of the fauna collected by the Wortman party. He dated the red-banded beds as Early Eocene and equated them to the fossiliferous part of the Wasatch group in southwestern Wyoming and northeastern Utah. Cope proposed a lacustrine mode of origin for the Big Horn "Wasatch" deposits and postulated the existence of a great "Wasatch" lake stretching from New Mexico northward through Wyoming. Wortman (in Cope, 1882) further discussed the geology of the basin and presented the first geologic map depicting the exposure of the "Wasatch". Osborn and Wortman (1892) added to the described mammalian fauna from the basin and concurred with the lacustrine origin of the strata.

Revision's of Wortman's map were published by Eldridge (1897) and Fisher (1906). Fisher's studies of the Tertiary red beds led him to postulate a fluvial rather than lacustrine mode of origin of Cope and others.

Numerous fossil-collecting expeditions visited the Big Horn Basin during the early years of the twentieth century, and the area became well known for its excellent mammalian remains. Loomis, while working with the 1906 Amherst collection from the "Wasatch" beds, noted the predominance of terrestrial fauna. He determined that 77 percent of the total fauna were land animals, whereas, in a typical lake basin, only 10 to 14 percent would be expected to be terrestrial forms (Loomis, 1907). Loomis concluded that the depositional environment of the Big Horn "Wasatch" was that of streams and flood plains, agreeing with Fisher's earlier fluvial interpretation.

Studies of the mammalian fauna of the Early Eocene strata of the basin and other Cenozoic deposits led Osborn (1909) to establish a series of "life zones" within the Cenozoic Era, with each zone typified by a supposed "guide fossil". The "Wasatch" deposits were assigned by Osborn to the "second faunal stage" and designated as the Coryphodon zone. However, subsequent information on the fauna extended the range of Osborn's "guide fossils" and frequent revision soon became necessary (Van Houten, 1944).

Much of the present knowledge on the red-banded strata of the Big Horn Basin has come from the efforts of W. J. Sinclair and W. Granger. From 1910 to 1914 they conducted a comprehensive study of the "Wasatch" deposits, and attempted to interpret the depositional environment by analyzing both the sediments and fossils. In their report of 1911, three faunal horizons, designated one, two, and three, were defined. These horizons consisted of a series of stratigraphic levels, with each level containing a sufficiently distinct faunal assemblage. In 1912 they further defined these faunal horizons and applied geographic names to them to avoid confusion with Osborn's "life zones". They were designated, from oldest to youngest, the Knight, Lysite, and Lost Cabin "formations".

In 1914 Granger discovered that the known fauna of typical Knight deposits outside the basin resembled more closely that of the Lysite faunal horizon. He therefore proposed the name Gray Bull to replace the Knight beds. Granger also recognized and named two other distinct faunal horizons in the Big Horn Basin "Wasatch". One of these, the Clark Fork beds, was found to be older than the Gray Bull and thought to be possibly of Late Paleocene age. The other faunal unit was termed Sand Coulee and placed between the Clark Fork and Gray Bull faunal horizons.

Hewett and Lupton (1917) and Hewett (1926) recognized and reported on the Gray Bull, Lysite, and Lost Cabin faunal units in the "Wasatch" of the southern Big Horn Basin.

Osborn (1929) recognized the five faunal horizons of Sinclair and Granger and applied them to his earlier concept of Cenozoic "life zones". In 1930 Jepsen reported on undescribed fauna secured from the Gray Bull horizon. Stow (1938) carried out a detailed petrographic study of heavy minerals found in the "Wasatch" of the Big Horn Basin in conjunction with dating Cretaceous-Eocene tectonic movements.

The most recent comprehensive study of the "Wasatch" strata in the basin was undertaken by Van Houten in the late 30's. He (Van Houten, 1944, p. 176) noted the confused usage of the term "Wasatch" and stated that:

To give the red-banded formation in the Big Horn Basin a new name, indicating within it the presence of distinct fauna, would most clearly express the nature of the sedimentary and fossil record and would also differentiate those variegated beds from other deposits in the Rocky Mountain region which they resemble only because of similar mode of origin.

Van Houten proposed the name Willwood Formation, after exposures along Willwood Divide in Park County, Wyoming, to replace the term "Wasatch" in the Big Horn Basin and to include those deposits yielding mammalian fossils from the Clark Fork through the Lost Cabin faunal horizons. His discussion of the stratigraphy of the Willwood consisted primarily of a description of twenty-one widely separated localities throughout the basin. Distinctive features of the strata at each locality were noted.

Other articles dealing with the Willwood Formation were published by Van Houten (1945, 1948, 1952), and Jepsen and Van Houten (1947). For the most part they consisted of paleontological studies and reviews of previous works. Van Houten's work of 1948 dealt with the origin of red-banded strata throughout the Rocky Mountain region, and much of the information presented was based on his studies of the Willwood Formation. He discussed at length the source and depositional environment of the fluvial sediments.

The most recent information on the Willwood Formation of the Big Horn Basin was published by W. L. Rohrer and C. L. Gazin. Rohrer (1964) mapped in detail the geology of the Sheep Mountain and Tatman Mountain areas. Rohrer and Gazin (1965) attempted to better define the Gray Bull and Lysite faunal horizons of the Willwood Formation. Their report contained an extensive fossil listing and a map of various fossil localities in the Sheep and Tatman Mountain areas.

Chart 1. Development of terminology associated with the Willwood Formation.

Epoch	Age	Cope 1882	Loomis 1907	Osborn 1909	Sinclair and Granger 1912	Granger 1914	Osborn 1929	Wood et al. 1941	Van Houten 1945
Early Eocene	late	Wasatch group	Big Horn Wind River formation	Coryphodon zone	Lost Cabin formation	Lost Cabin beds	"Big Horn E" <i>Lambdasterium</i> zone	Lost Cabin Equiv.	Lost Cabin Faunal Zone
	middle		"Wasatch" formation		Wind River	Lysite beds	"Big Horn D" <i>Heptodon</i> zone	Lysite Equiv.	Lysite Faunal Zone
					Wasatch	Gray Bull beds	"Big Horn C" <i>Systemodon</i> zone	Gray Bull member	Gray Bull Faunal Zone
Late Paleocene	Clark-forkian					Clark Fork beds	"Big Horn B" <i>Eohippus</i> zone	Sand Coulee local fauna	Willwood Formation
							"Big Horn A" <i>Phenacodus</i> zone	Clark Fork member	Polecat Bench Fm.

NOMENCLATURE

The development of terminology pertaining to the Willwood has often been ambiguous and confusing. Much of the nomenclature has been inadequately defined, and seldom have the stratal and faunal subdivisions been clearly distinguished (Van Houten, 1944). Prior to the development of the Code of Stratigraphic Nomenclature (Ashley, et al., 1933) the various schools of stratigraphy were not in complete agreement as to the definition and application of stratigraphic terminology. Units such as "formation", "member", or "assemblage zone" did not exist in a standardized form, and guidelines for their use as rock-stratigraphic or biostratigraphic units were lacking during the early years of their application.

For many years the Willwood was designated as the Big Horn "Wasatch" formation, a name originally applied by Hayden (1869) to red-banded strata exposed near Wasatch Station, Summit County, Utah and later extended to include widely separated, red-banded deposits throughout the Rocky Mountain region. Although it became apparent that many of these deposits had accumulated at different geologic time intervals as distinct and tectonically isolated deposits similar only in their mode of origin, the term "Wasatch" continued in use. With the establishment of the Code of Stratigraphic Nomenclature and formal recognition of "formation" as a rock-stratigraphic unit, revision of much of the "Wasatch" nomenclature

became necessary. The designation of Willwood Formation to replace "Wasatch" in the Big Horn Basin represents such a revision.

The absence of definite lithologic boundaries within the Willwood Formation resulted in early subdivision and correlation to be based primarily on "faunal zones", which represent particular intervals of strata defined solely on fossil content. These "faunal zones" were often expressed as "formations" or "members", which would imply they were also definable on a lithologic basis. However, their recognition and stratigraphic utilization were based on the discovery and proper identification of particular fauna. As the number and vertical range of individual fossil taxons associated with particular "faunal zones" increased, revision became necessary.

The Code of Stratigraphic Nomenclature (Ashley, et al., 1933) stated that "a unit distinguished from the enclosing rocks only by its fossils shall not, in general, constitute a formation". It also stated that "a unit distinguished only by its fossils is not a rock-stratigraphic unit but is properly classified as a biostratigraphic unit". More recent studies of the Willwood Formation and similar deposits have followed this principle. The present subdivisions of the Willwood (Clark Fork, Gray Bull, Lysite, and Lost Cabin "faunal zones") are considered biostratigraphic units, with each zone characterized by specific differences of certain

genera common to more than one zone, and by the presence or absence of certain genera (Rohrer and Gazin, 1965). Although each of these faunal horizons is assigned a particular thickness, such dimensions are based on faunal content rather than lithologic factors.

STRATIGRAPHY

General Statement

The Willwood Formation, as defined by Van Houten (1944), consists of a series of red-banded, fluviatile sediments, ranging in age from Late Paleocene to Early Eocene, exposed over a large area of the Big Horn Basin. The thickness of the Formation varies, with thicker portions found in the central part of the Basin. Estimates of maximum thickness have varied, however, 2500 feet has become accepted as a close approximation (Van Houten, 1944). In most areas a large amount of Willwood strata has been removed by late Cenozoic erosion.

A composite section of the Willwood Formation and its relationship to other lower Tertiary sediments is shown in fig. 3. Over much of the central portion of the basin the Willwood conformably overlies the Paleocene Polecat Bench (Fort Union) Formation. This conformable relationship grades laterally toward the basin margin into an angular relationship. In a few instances the Willwood is observed to completely truncate the Polecat Bench and rest upon Upper Cretaceous rocks (Van Houten, 1944).

The establishment of a suitable contact separating the Willwood and Polecat Bench Formations in areas of conformity has been a problem. The change from drab Polecat Bench deposits

Fig. 3. A composite section of the lower Tertiary sediments in the Big Horn Basin. Dashed lines indicate boundaries and approximate thickness of Willwood Faunal Zones.

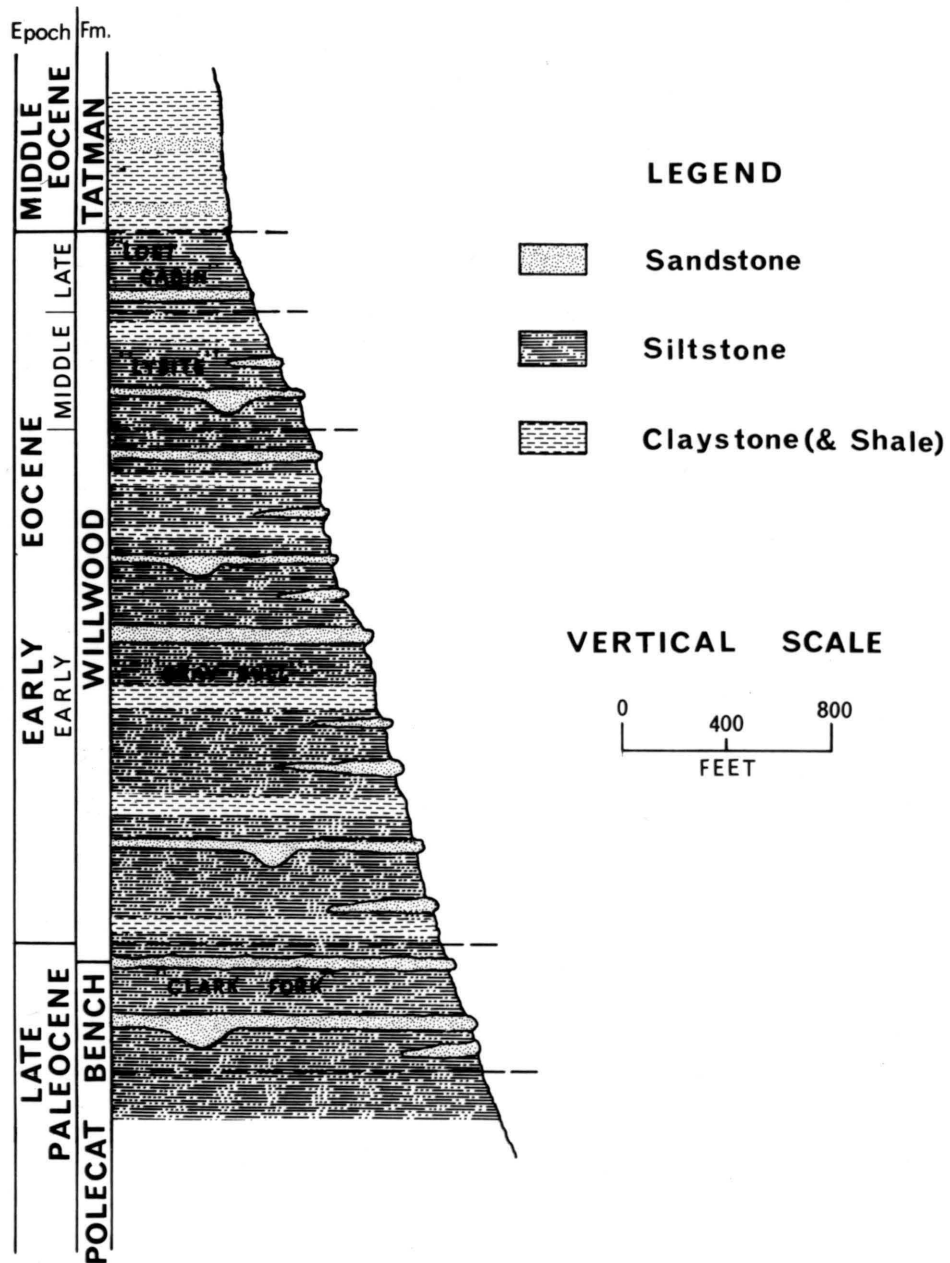


FIG. 3 COMPOSITE SECTION
OF LOWER TERTIARY SEDIMENTS,
BIG HORN BASIN, WYOMING

to red-banded Willwood strata is gradational, and no conspicuous change in lithology separating the two has been noted to date. Two methods have been proposed to establish a suitable boundary. Stow (1938) noted the sudden appearance of hornblende in Willwood strata. Van Houten (1944) suggests that the principal physical change marking the beginning of Willwood deposition is the first occurrence of red-banding.

The Tatman Formation, Middle Eocene in age, conformably overlies the Willwood Formation. The contact between the two units is also gradational in nature and is represented by a transitional zone of red siltstone and claystone lenses interbedded with brown carbonaceous shales (Van Houten, 1944).

Stratigraphic Relationships

The Willwood sediments exposed in the area of study consist of a series of channel sandstones and varicolored siltstones and claystones (figs. 4 and 5). The beds are essentially horizontal and extend laterally for distances ranging from several 100 feet to a mile or more. When viewed from a distance, color-banding of the strata results in a homogeneous appearance. Close examination, however, reveals a more complex nature. Lateral and vertical changes in lithology are generally gradational, and the beds interfinger over relatively short lateral distances.

The Willwood Formation presents to the observer a heterogeneous and complex association of sediments in which comparative

Fig. 4. Photographs of the Willwood Formation exposed in the study area.

- A. Willwood strata on the slopes of Sheep Mountain.

- B. An eroded channel sandstone is exposed in the foreground. Less resistant units along the vertical exposure are fine-grained siltstones and claystones, whereas thin, resistant units are "sheet" sandstones.

- C. View of the cut-and-fill relationship formed by erosion of a stream channel into underlying sediments followed by filling of the channel with sand-sized material. The discordant boundary of the channel sandstone and truncated, underlying strata is drawn.

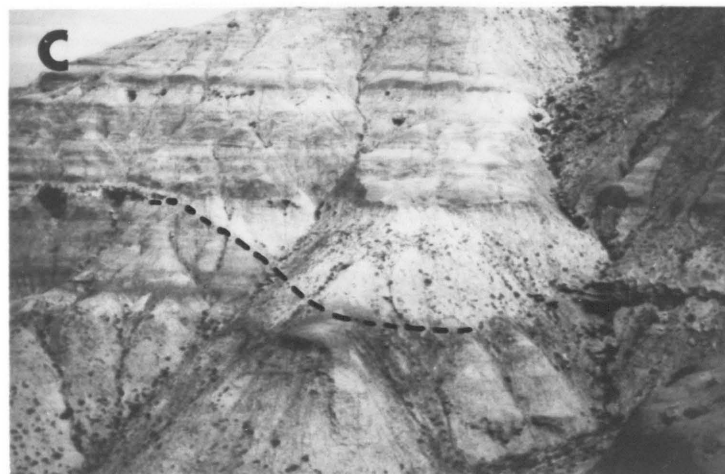
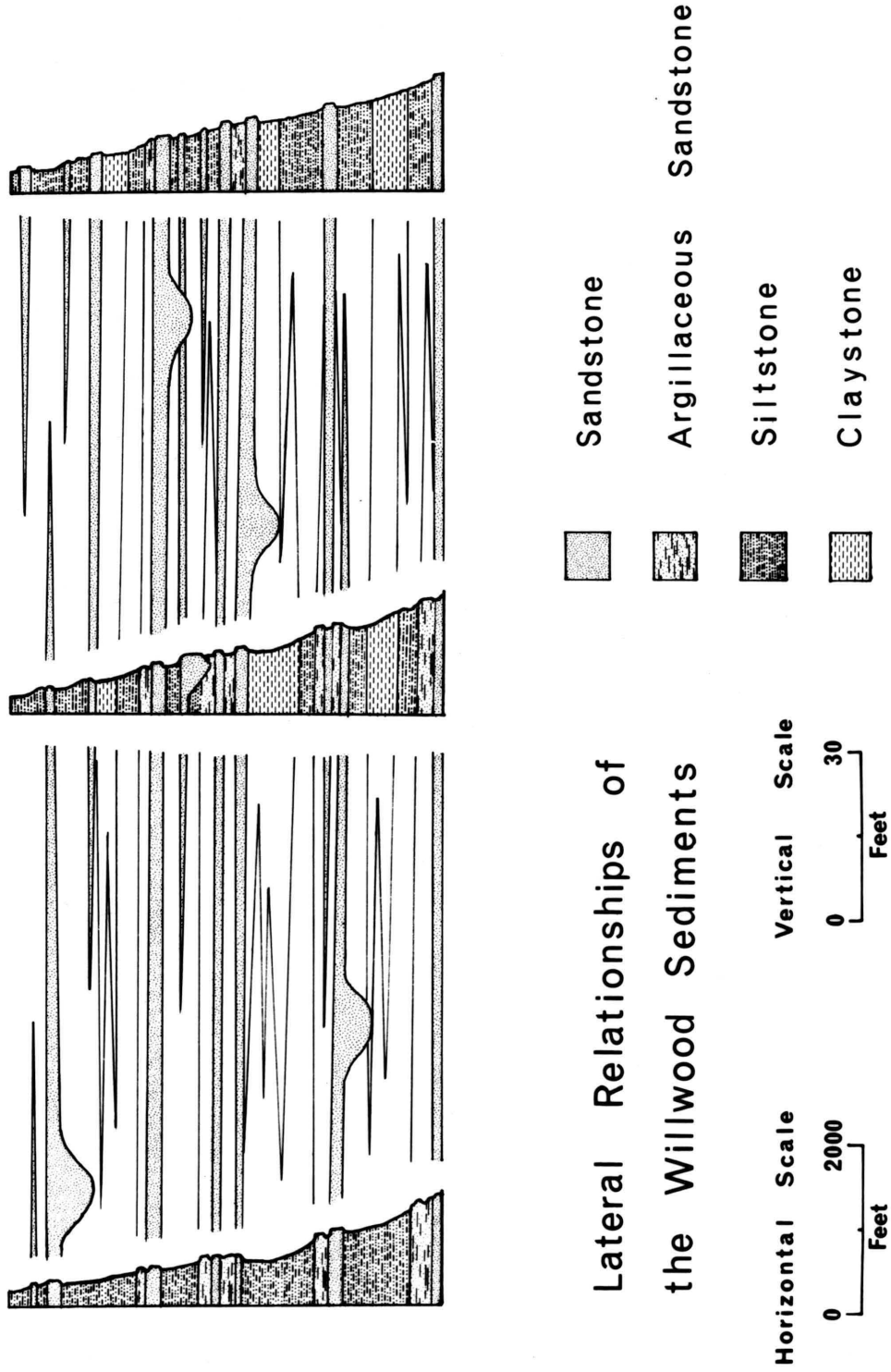


Fig 5. Diagram showing lateral relationships of the Willwood sediments. The stratigraphy between the measured sections is interpretative, and has been constructed to illustrate the general nature of the strata.

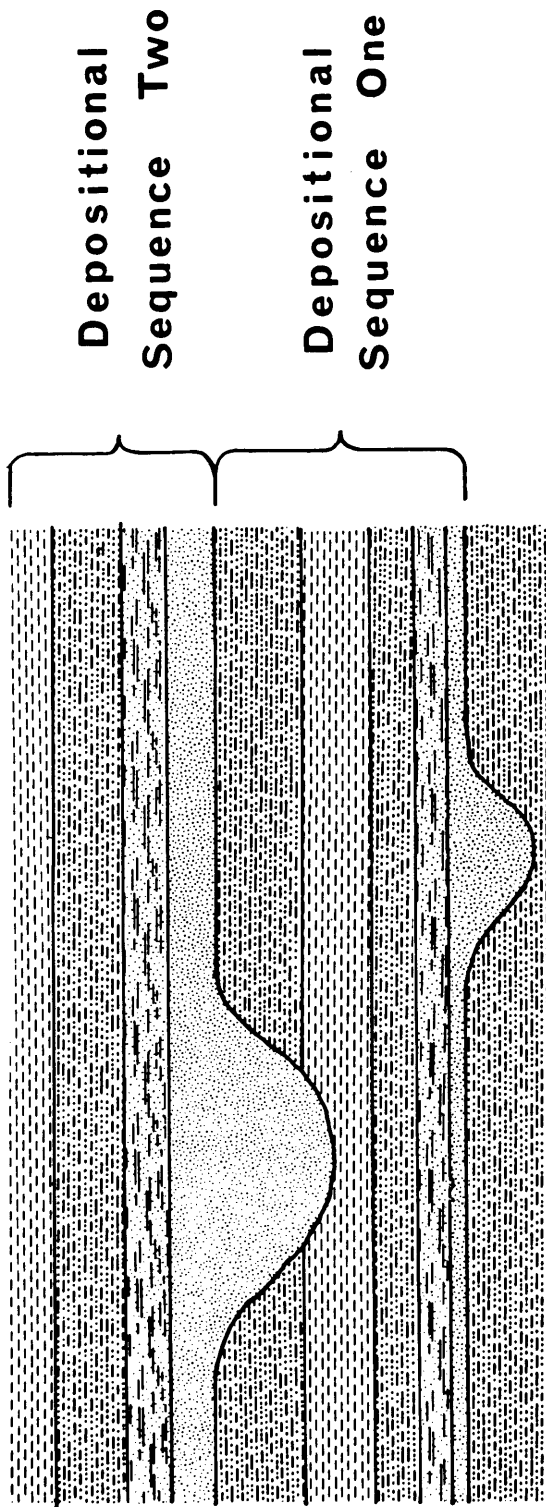


studies of exposures are difficult. In discussing the character of the sediments in a systematic manner, the writer has determined certain, common, stratigraphic relationships and consolidated them into an "idealized" Willwood depositional sequence (fig. 6). Particular lithologic and stratigraphic features illustrated in the diagram were observed in many measured sections and have a repetitive nature warranting particular attention. Although the stratigraphic model is hypothetical and variations exist, it presents the basic nature of the Willwood sediments.

The basal and most prominent member of a depositional sequence is a sandstone unit. It consists of a main channel sandstone and related, laterally extending, "sheet" sandstones. The channel is plano-convex in shape and occupies a shallow, linear depression eroded into older, underlying sediments. The width of the channel varies from 5 feet to 50 feet, and thickness ranges from 1 or 2 feet to occasional occurrences of around 35 feet. The "sheet" sandstones extend laterally from the upper portions of the channel for distances ranging up to a half mile or more. They are characterized by thin units of relatively uniform thickness and lithology and consist of sandstones of a finer grade than those of the main channel.

The basal sandstone unit grades upward into progressively finer-grained sediments. Commonly a red or maroon fine-grained sandstone or siltstone, grading vertically into a lavender siltstone, lies immediately above the channel sand.

Fig. 6. Model of an "idealized", Willwood, repetitive sequence, representing a consolidation of common stratigraphic features into a single sequence of channel sandstones and associated siltstones and claystones.



Idealized Sequence
of Willwood Strata

Overlying these units are siltstones and claystones. The proportion of silt- and clay-size particles varies, and a variety of fine-grained, lithologic types characterizes this particular interval of strata. Color is variable, but yellowish-browns and grayish-greens predominate. The sequence is capped by a red or maroon, silty claystone grading upwards to a lavender, silty claystone. The two units are overlain by a channel sandstone, which marks the initiation of a new depositional sequence. The upper, maroon and lavender beds are often completely truncated by the channel, with the cut-and-fill relationship extending several feet into the underlying strata. The discordant contact is occasionally marked by a thin greenish-gray, sandy claystone, which appears to represent reworked material deposited as the channel cut into the underlying sediment.

Common lithologic variations of the "idealized" sequence are represented by numerous sandstone lenses associated with either the main channel sandstone or the siltstone-claystone portions of the sequence. Beds other than the red and lavender units may be truncated by the overlying channel sandstone. Such variations result either from fluctuations in the normal sequence of deposition represented by the model or by the interfingering of two or more depositional sequences.

Key Beds

Fossil evidence today serves as the only method of

establishing stratigraphic relationships between widely separated areas. Sediments from a given locale containing fossils of either the Clark Fork or Gray Bull Faunal Zones are considered to belong to the lower portion of the Willwood Formation, whereas sediments of another area yielding Lysite or Lost Cabin fossils are identified as younger in age and occurring higher stratigraphically. Such methods, however, allow only for correlation of thick sequences of strata associated with the faunal horizons and are dependent on the ability of the observer to both find and identify fossils characteristic of the particular faunal zones.

The solution to the problem is to subdivide the Willwood into smaller formal rock units. Each unit would be characterized by a distinctive lithologic nature independent of fossil content and identifiable over a large area. The units would provide for a much improved method of correlating strata from one locality to another, and relative stratigraphic position of fossils from different localities could be better established.

In order to establish meaningful stratigraphic relationships between exposures of Willwood strata, some basis of lateral equivalence must be developed. In the present study this was accomplished by the "walking out" of individual beds. Where this is either impossible or impractical, comparative lithologic and stratigraphic studies were exceedingly difficult. The writer has attempted to establish certain key beds in the

Willwood that may be of significant value to the problem of correlating strata. If reliable and practical methods of stratigraphic correlation through the use of such beds can be developed within an area the size of the study area, such techniques could be extended to other portions of the basin, and subdivision of the red-banded deposits into smaller rock-stratigraphic units could be approached on a sound basis.

Two types of rock-units were observed that appear to contain characteristics indicating that they and/or similar units could be of value as key beds. One was a sandstone complex of some 40 feet in thickness that formed a prominent topographic bench in the vicinity of measured sections number six and eleven (see fig. 2). The bench was traced laterally for over a mile, and, due to the rugged topography of the Sheep Mountain area, was evident on both standard topographic maps and aerial photos of the area.

In their report of 1911, Sinclair and Granger noted the presence of a bench in the Willwood strata extending horizontally along Sheep Mountain for 3 or 4 miles. The writer believes the presence of these erosional topographic features is related to the occurrence of an unusually thick sandstone complex that extends over a large area. If such a relationship could be established through aerial photo studies and field observations, stratigraphic sections removed from one another that contain such a feature could be correlated.

The other type of rock unit considered as potential key or marker beds was certain lavender-colored, siltstone-claystone units. These units, rarely greater than 1 or 2 feet thick, occurred in association with red or maroon beds of similar lithology. The lavender units were valuable in local correlations of sections, for their color was usually quite evident in vertical exposures and easily traceable laterally. Often several of these beds could be traced between exposures, permitting detailed correlation of many units.

The "walking out" of these lavender siltstone-claystone beds revealed that some extend laterally for 2 or 3 miles and more. Other reports on the Willwood Formation noted similar occurrences. Sinclair and Granger (1911, p. 114) reported that

beds are lenticular in shape..., traceable sometimes for several hundred yards to a mile or more. One persistent purplish band, passing over the Elk Creek Anticline, may be followed for several miles.

Rohrer and Gazin (1965, p. 134) discussed the presence in the Sheep and Tatman Mountain area of a

purplish-maroon claystone...generally about three feet thick, but it ranges from two to ten feet in thickness...locally containing thin lenses of sandstone...which crops out over more than seventy square miles.

They designated this unit as "Bed A" and were of the opinion that it extends beyond the Tatman and Sheep Mountain area.

It appears to the writer that "Bed A" and possibly other major lavender siltstone-claystone units can be of value as key

beds for correlation over wide areas. The identification of "Bed A" in isolated areas is aided by the fact that it has been found by Rohrer and Gazin (1965) to contain a rather distinct fossil assemblage considered as a molluscan zonule locally containing fragments of mammals. Thus its existence as both a rock-stratigraphic unit extending over a large area and a bio-stratigraphic unit recognizable by its fossil content could be of significant value in stratigraphic correlation of Willwood strata.

LITHOLOGY

The mineralogical components of the Willwood Formation consist essentially of quartz grains and various clay minerals together with smaller portions of feldspars and "heavy" minerals. These constituents are combined in varying amounts and textures to give the over-all lithology of the red-banded strata a variable nature.

Sandstones

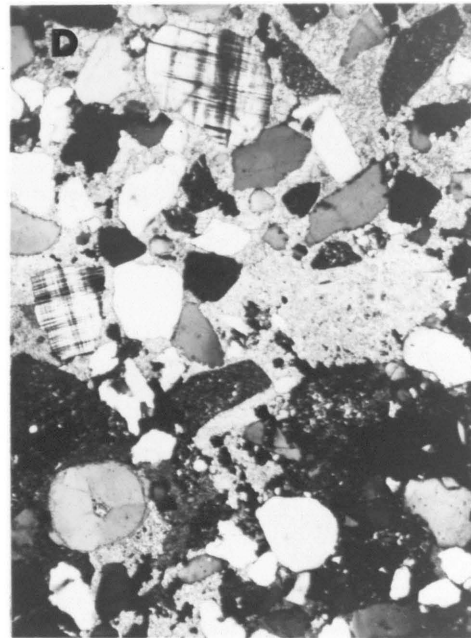
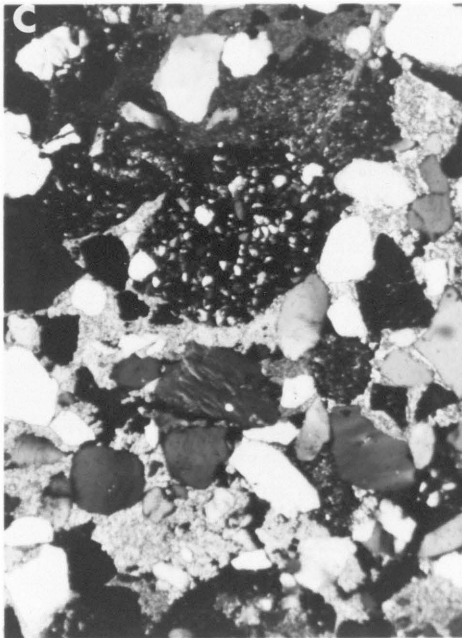
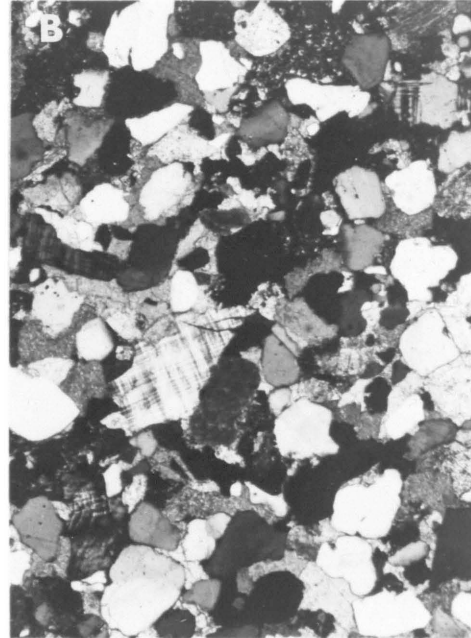
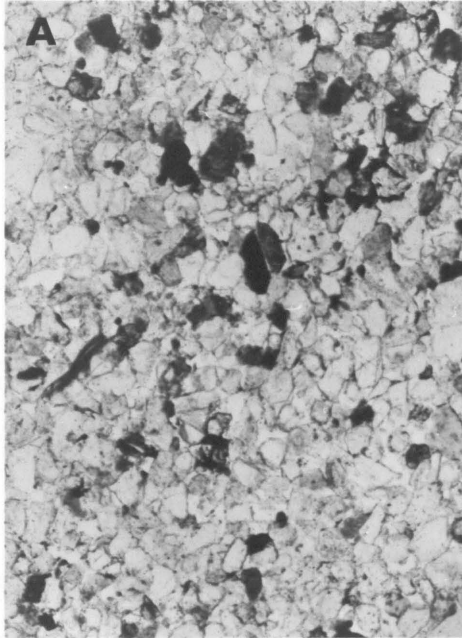
The Willwood sandstones can for the most part be classified as protoquartzites (Pettijohn, 1957), which are characterized by 75% to 95% quartz content, rock fragments exceeding feldspar grains, and rock interstices essentially void or filled with carbonate cement (fig. 7). Variations to this compositional nature are reflected in increasing detrital matrix, reduction in the amount of carbonate cement, and a greater portion of rock fragments relative to quartz grains.

The color of the Willwood sandstones ranges from white to gray and yellowish buff. Occasional units display coloring typical of the siltstones and claystones, with red, lavender, brown, and olive-green colors occurring individually or together in a mottled pattern.

Textural properties include a general size range for the sand particles of from medium through very-fine grades (1/2 mm. - 1/16 mm.) on the Wentworth scale. Coarse-size particles of

Fig. 7. Photomicrographs of Willwood sandstones.

- A. Sample 10-1-73. Ordinary light, 25X. Relative portions of opaques (various "heavy" minerals) and non-opaques (predominately quartz and feldspars).
- B. Sample 10-2-18. Crossed nicols, 25X. "Typical" sandstone texture. Subrounded quartz grains and feldspars (microcline shown) are etched by carbonate cement binding them together.
- C. Sample 10-1-18. Crossed nicols, 25X. Quartz, chert, and feldspar (perthite shown) set in a calcite matrix.
- D. Sample 10-2-33. Crossed nicols, 25X. Quartz, chert, and microcline surrounded by a relatively large amount of carbonate cement.

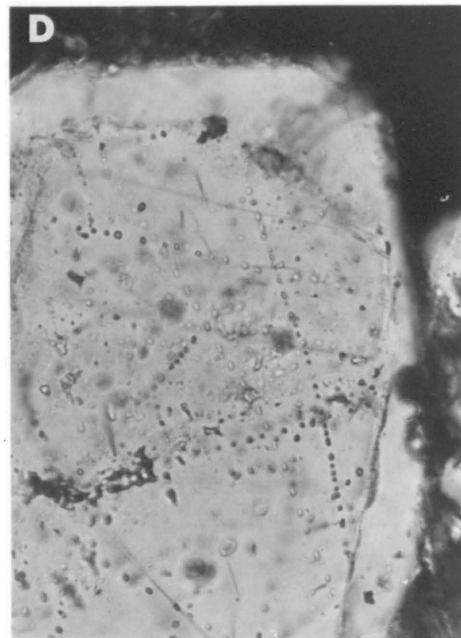
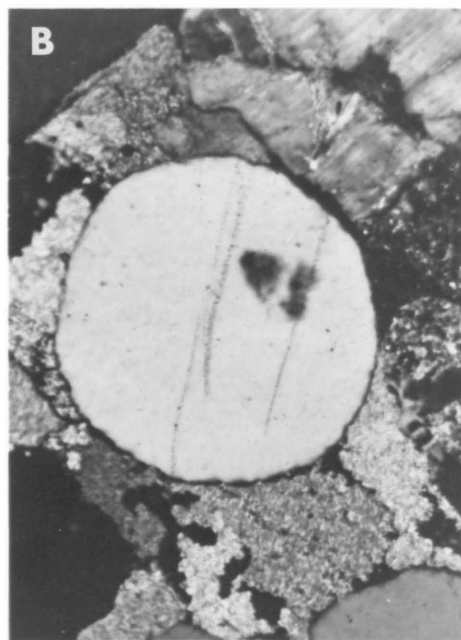


one millimeter in diameter were also noted in a few samples. Analysis of three "typical" Willwood sandstones revealed the presence of one dominant or "modal" class, constituting approximately 60% of each sample, occurring in the 1/4 mm. - 1/8 mm. particle size range (fine sand). Sorting coefficients of the samples analyzed were indicative of moderate to moderately-well sorted sediments. Particle shape was variable, with most sand-sized grains displaying some evidence of rounding. However, within samples angular grains indicative of little abrasive action and grains extremely well rounded and possessing near-perfect spherical shapes were observed (figs. 8A and 8B). Many of the larger, well-rounded, quartz grains have frosted and polished surfaces and are indicative of "reworked" grains derived from pre-existing sedimentary sandstone units.

The mineralogical constituents of the Willwood sandstones consist essentially of quartz, potash and plagioclase feldspars, and various "heavy" minerals in a matrix of silt- and clay-sized particles and authigenic calcite cement. Quartz is predominant in all samples examined. Various grains display evidence of strain with well-developed undulatory extinction and numerous "bubble trains" (figs. 8C and 8D), features generally characteristic of metamorphic quartz (Pettijohn, 1957). Embayments of calcite cement into quartz grains indicates secondary solution and replacement. Replacement of

Fig. 8. Willwood sandstones.

- A. Sample 7-3-57. Crossed nicols, 25X. Variations in particle shape within one sample. The well-rounded nature of the quartz grain at the top contrasts sharply with the angular nature of the grain in the lower portion of the photo.
- B. Sample 7-3-57. Crossed nicols, 63X. Quartz grain displaying a well-rounded and near-perfect spherical nature. Surrounding material is predominately carbonate cement.
- C. Sample 7-3-57. Crossed nicols, 63X. Highly strained, quartz grained displaying sharp, undulatory extinction.
- D. Sample 7-2-69. Crossed nicols, 400X. Secondary quartz overgrowth on quartz grains. Bubble train terminations and dark traces locate original grain-overgrowth boundary.



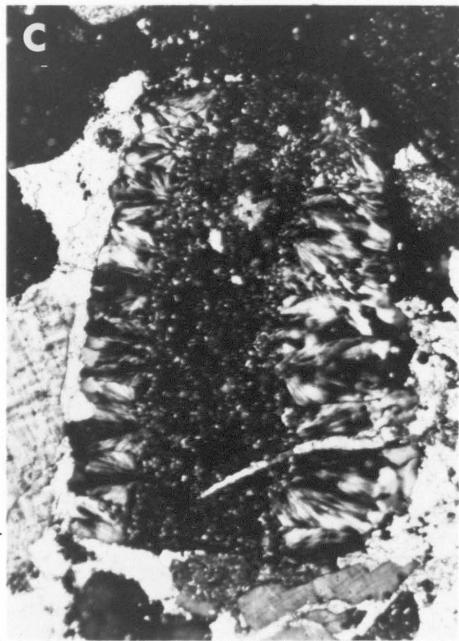
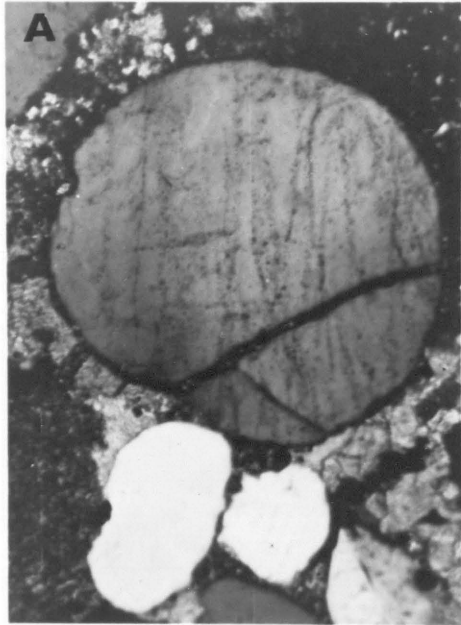
quartz is also evidenced by small, isolated "islands" of quartz surrounded by calcite, and the complete mass having the shape of a relict grain (fig. 9D). Other varieties of silica include numerous chert grains and rare occurrences of chalcedony (fig. 9C).

Secondary overgrowths on quartz grains (fig. 8D) are apparent both in megascopic and microscopic examination of the sandstones. In disaggregated samples numerous singly and doubly terminated quartz crystals were detected through their characteristic shape and reflection of light from crystal facets. The boundary of the overgrowths and original grains is commonly represented by both intermittent dark traces representing silt and clay particles on the original grain surface, and by termination of "bubble trains". That these growths were secondary to formation of the sand units is indicated by the well-developed crystal facets and terminations showing no evidence of abrasion.

The feldspars contained in the Willwood sandstones studied are primarily potash varieties, with orthoclase and microcline present in most thin-sections. Occasional grains of plagioclase feldspar were also detected. Perthite intergrowths occur in some of the feldspar grains, and instances of unmixing by the microcline-albite components were noted. As with the quartz grains, replacement of the feldspars by calcite cement has occurred.

Fig. 9. Willwood sandstones.

- A. Sample 7-3-57. Crossed nicols, 63X. Well-rounded quartz grain displaying fracturing subsequent to deposition.
- B. Sample 10-2-33. Crossed nicols, 100X. Post-depositional compression of a muscovite particle between quartz grains
- C. Sample 7-3-57. Crossed nicols, 63X. Detrital grain displaying partial replacement of chert by chalcedony. The grain surface has been etched by carbonate cement.
- D. Sample 7-3-57. Crossed nicols, 25X. "Relict" quartz grain presently represented by small, isolated, quartz particles surrounded by carbonate cement, and the entire mass having the shape of a detrital grain.



The "heavy" minerals generally constitute from 5% to 10% of the sample. Although separation of the "heavies" was not made, several varieties were identified. Magnetite was found to be a common opaque mineral, and abundant non-opaques included garnet, zircon, muscovite and biotite, hornblende, and chlorite. These minerals are common to both igneous and metamorphic rocks and, together with quartz and feldspar grains, indicate a crystalline source for much of the Willwood sediment.

The bedding of the sandstones is massive and uniform, and jointing has caused many units to weather into large, rectangular blocks. Evidence of current cross-bedding was observable in thick units, but weathering of the relatively friable rock made quantitative measurements impossible. Ellipsoidal, concretionary sand bodies, generally 1 foot in diameter, were encountered at a few sandstone exposures.

Sandstone dikes occur at various stratigraphic intervals in the area of study. Their exposure consisted of a narrow, vertical ridge protruding several inches above the eroded, enclosing strata. The clastic dikes are interpreted as penecontemporaneous structures brought about by either the filling of fissures with sand derived from beds higher in the section (Wanless, 1923) or intrusion of unconsolidated sand into overlying material (Sinclair and Granger, 1911).

Trace fossils were present in many of the "sheet" sandstones and occurred as tubular structures ranging up to 30 mm.

in diameter. The "tubes" usually consist of sand-sized particles lithologically indistinguishable from the surrounding matrix (fig. 10A). However, some were observed that contain silt- and clay-sized material (fig. 10B). The "tubes" have a vertical to subvertical orientation, and differential weathering caused many to be preferentially eroded from the surrounding sand matrix (fig. 10C). Weathering of individual trace fossils often results in a distinct, transverse, concave-upward structure. The pattern apparently represents the filling of the tubular features by material of an alternating and differing lithology, with less resistant layers containing a higher silt and clay content and/or less chemical cement.

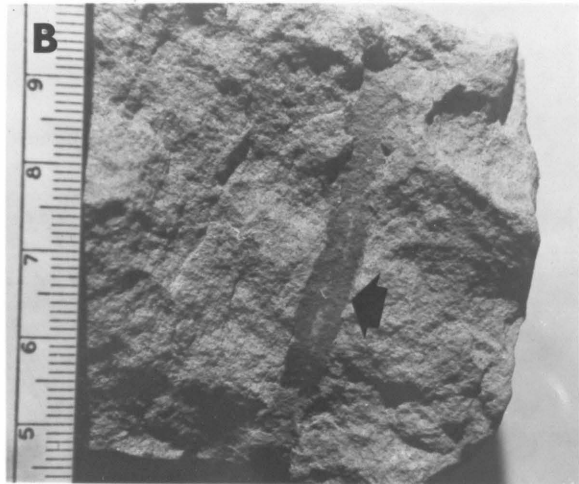
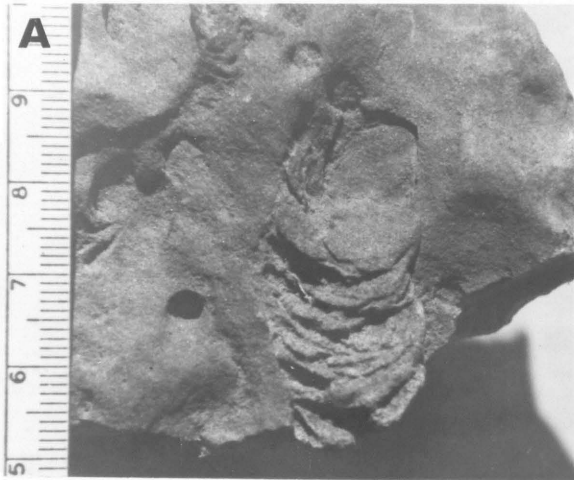
The trace fossils resemble habitation burrows related by Ager (1963) to pelecypods. The association with "sheet" sandstones indicates the site of development was outside the main stream channel in a more "calm" and shallow water environment. Fluctuations in the competence of the stream would account for alternating lithology of the sediment filling the burrow.

Siltstones and Claystones

The fine-grained Willwood sediments consist of a mixture of silt- and clay-sized particles in a matrix of clay and iron-oxide minerals. The clastic portion of the siltstone-claystone units contains essentially the same minerals as the sandstones, and quartz was predominant in 20 samples analyzed with the

Fig. 10. Trace fossils and concretions of the Willwood Formation. (scale in centimeters)

- A. Burrow in sandstone filled with sand-size particles and displaying concave-upward structure.
- B. Burrow in sandstone filled with silt- and clay-sized sediment.
- C. Tubular structures (burrow fillings) which have been eroded from the surrounding matrix. (scale same as D)
- D. Calcareous concretions common to the siltstones and claystones of the Willwood Formation.



X-ray diffractometer. Clay minerals detected include illite, montmorillinite, and kaolinite, with many samples containing all three.

The color of the fine-grained sediments is attributed to the nature of the pigment in the clay-sized fraction occupying the interstices between individual grains (Van Houten, 1948). The pigment color is due to the type of iron-oxide minerals present, the ferric-ferrous ratio, and degree of hydration. Red colors are attributed to the anhydrous, ferric oxide, hematite (Fe_2O_3), and indicative of oxidizing conditions at the site of deposition. Hydration of ferric oxide ($\text{Fe}_2\text{O}_3 \cdot n\text{H}_2\text{O}$) is associated with yellowish-brown and rust colored pigments. Drab colors (olive-green and gray) are interpreted as representative of reducing environmental conditions and the presence of ferrous iron oxide (FeO).

Van Houten (1961) presents the following points on the relationship of iron content and rock color.

1. There is a greater amount of both total iron and ferric iron in most red rocks as compared with non-red rocks. In two samples from the same formation the red sample contains more ferric oxide than the drab sample.
2. Most red rocks contain a $\text{Fe}_2\text{O}_3:\text{FeO}$ ratio greater than two. Drab rocks have a $\text{Fe}_2\text{O}_3:\text{FeO}$ ratio generally less than two.

3. Drab rocks appear to represent reduction of ferric iron to ferrous iron and/or its removal from the rock through solution.

The coloration of siltstones and claystones in the Willwood Formation is generally expressed in one of two ways; (1) one color permeating the entire mass, and (2) a mottled pattern with irregular patches of two or more colors randomly distributed throughout. Maroon and gray colors are commonly associated with the massive colored beds. Assuming the sedimentary material contained a ferric oxide pigment (red) when delivered to the depositional site (Van Houten, 1948), the red units represent a minimal amount of reduction and/or removal of ferric oxide, whereas gray sediments represent a high degree of reduction and alteration of the original ferric nature of the pigment. A broad transition zone of rocks representative of intermediate stages in the alteration of the original sediment occur between these two coloration "end members". Such units generally exist as mottled beds displaying a variety of color combinations.

Many of the mottled units contain evidence of organic activity. Tubular structures resembling worm burrows and measuring up to 5 mm. in diameter occur in the varicolored fine-grained beds (fig. 11A). They are evident through both the contrasting color of the "mud" filling the burrows with that of adjacent material and the irregular, transverse

Fig. 11. Organic and inorganic features of the fine-grained Willwood sediments. (scale in centimeters)

- A. A claystone unit that displays evidence of organic activity. Arrow points to a "tube" which contains irregular layers and resembles a worm burrow. In the upper portion of the sample, (a) designates the trace of black, carbonaceous material resembling a plant root. Sediment at (b) is greenish-gray (reduced) and contains sand-sized particles. Sediment at (c) is lavender. In the area of (d) red, lavender, and yellowish-brown colors are present in a mottled pattern.

- B. A gray claystone containing a network of black filaments resembling an intricate root pattern.

- C. A carbonaceous shale that contains preserved plant material, described by Dr. John Mickel of the Iowa State University Botany Department as a palmately lobed, dicot leaf.

- D. "Slickenside" surfaces present on portions of the claystone sample, the result of post-depositional compaction of Willwood sediments.



layers alternating in color within the tube. The presence of thin, black, carbonaceous "threads" occurring either singularly or together in an intricate network represents preserved plant material (figs. 11A and 11B). Sediment adjacent to the organic "threads" has been altered (reduced) to a greenish-gray color.

The "mixing" effect of such organic activity may be a significant factor in the chemical alteration and mottling of the fine-grained Willwood sediments. Besides contributing organic material to the sediment favorable for the development of reducing conditions, the continuous "reworking" action of organisms coupled with root penetration could cause incorporation of sediment of one color with underlying material of a differing color.

Concretionary iron oxide and calcium carbonate structures developed in some of the fine-grained strata. Carbonate concretions occur either as individual nodules (fig. 10D) and nodular aggregates eroded from the strata and covering the ground surface or as encrustations on fossil fragments. X-ray analysis showed a significant amount of barite (BaSO_4) within the carbonate concretions. The iron oxide concretions are present in small pisolitic bodies 1 to 5 mm. in diameter and occur with particular abundance in mottled lavender units. They have a rust-colored core, and X-ray analysis showed the presence of ferric oxide minerals.

The writer believes that the various features of color

mottling, worm and plant activity, and localized concentrations of minerals developed within unconsolidated or semi-consolidated material on or in close proximity to the surface of sediment deposition. Van Houten (1948) relates mottling to conditions of poor drainage and points out the similarity of mottled Willwood sediments to those of tropical soils resulting from alteration of red soil. The formation of concretions is often related to ground water activity. Iron concretions have been related (Soil Survey Staff, U. S. Department of Agriculture, 1951) to conditions of alternating oxidation and reduction, a situation that could exist in soils marked by variable drainage and ground water activity.

One of the most intriguing of the fine-grained Willwood sediments is a brownish-black, highly carbonaceous and argillaceous shale (fig. 11C) occurring in localized lenses. The lenticular deposits are very rich in fossilized wood and leaves. Much of the organic material occurs in "mats" and gives the shale a thinly laminated nature. The carbonaceous unit is underlain by a gray, silty claystone characterized by a blocky fracture, and it grades upwards into a grayish-brown claystone. Disseminated throughout the units is an unidentified, yellow, powdery material. The carbonaceous shale represents a localized swamp environment characterized by the accumulation and preservation of a large amount of organic material within silt and clay washed in from adjacent areas.

PALEONTOLOGY

The Willwood Formation, as well as other red-banded, early Cenozoic deposits of the Rocky Mountain intermontane basins, have yielded a rich assemblage of mammalian fauna representing one of the most complete Cenozoic collections in the world. The paleontological importance of these deposits is demonstrated by the fact that 42 genera "die out" and 54 genera, including representatives of many "modern" mammalian families, "appear" within the faunal zones of the Willwood Formation (Van Houten, 1945).

Information concerning the distribution of fossils in the Willwood indicates the following relationships between faunal type and lithology of the sediments (Van Houten, 1948).

1. Most fossils from drab sediments are concentrated in small pockets or "quarries" and are mainly small, forest-dwelling mammals.
2. Fossils collected from red beds are generally scattered throughout the matrix and are principally remains of terrestrial ungulates and carnivores.

The common occurrence of forest-dwelling fauna in drab sediments suggests a depositional area characterized by heavily wooded and swampy conditions. Local pockets of fossil material resulted from the concentration of many individuals, possibly along stream channels. The association of larger, terrestrial mammals with red units indicates a more open depositional area

similar to "parks" of a savannah-like environment. The fragmented nature of the fossils could have resulted from the action of scavengers and severe weathering conditions at the surface of sediment accumulation prior to burial.

ENVIRONMENT OF DEPOSITION

Previous studies (Loomis, 1907; Sinclair and Granger, 1911, Van Houten, 1944, 1948) have demonstrated that the red-banded Willwood Formation represents fluvial deposits of a piedmont and valley-flat environment. Van Houten (1948, p. 2103) states:

The available evidence points to the conclusion that these sediments were eroded from peripheral uplands during an early stage of the Laramide revolution when most of the alluvial material was deposited in tectonic basins which sank rapidly enough to maintain a lowland environment.

The present study has found no evidence to dispute such an hypothesis, with the exception that the orogeny associated with Willwood deposition should be considered as a late rather than early stage of the Laramide (Eardley, 1962).

Nature of the Source Area

Knowledge of the upland source area is largely acquired from the lithology of the sediments. The presence of detrital quartz, feldspar, and "heavy" minerals derived from sedimentary, igneous, and metamorphic rocks indicates that during Willwood times portions of the surrounding uplands were stripped of their sedimentary cover and Precambrian cores were exposed. Green hornblende in the Willwood sediments and its absence from older basin deposits suggests that the Early Acid Breccia of the Absaroka volcanics was also eroded during this time (Stow, 1938).

It is significant that, although crystalline rocks served as an important source and the distance of sediment transport from the upland regions to the basin lowlands was generally less than 100 miles, the Willwood rocks are relatively mature mineralogically. Weathering processes had sufficient time and intensity to breakdown and decompose much of the unstable mineral components (feldspars and "heavies"). Decomposition of the unstable minerals does not appear to have taken place at the site of deposition, for continual aggradation permitted little opportunity for intense weathering and alteration of surface material. Rather, the character of the Willwood sediments was largely determined by the nature of materials eroded in the source area.

The climate of the Rocky Mountain region during Willwood times was warm-temperate to sub-tropical, with heavy, seasonal precipitation in the upland areas (Van Houten, 1948). The relief of the area was not great, for mountains towering several 1000 feet above the basin surface would have greatly altered the climate. Floral and faunal evidence, however, records no major climate change throughout the Paleocene and Early Eocene (Van Houten, 1944). Erosion was able to keep pace with Laramide uplift in the surrounding uplands and maintain a relatively mature stage in the topography of the basin area.

Alternating moist and dry conditions coupled with warm

temperatures in the well-drained uplands were favorable for rapid decay of bedrock and formation of a deeply weathered regolith and lateritic soil (Van Houten, 1961). Intense weathering led to the rapid disintegration and decomposition of primary silicates and the complete oxidation of organic matter. Iron was oxidized, and ferric oxide (hematite) was concentrated in the upper portion of the weathering profile (Grim, 1953). Heavy, intermittent rains promoted erosion of the surface material by two basic methods. Sheet erosion stripped away strongly weathered, red soil and contributed fine-grained material and red pigment (hematite) as potential Willwood sediment. Gullying, on the other hand, cut through the weathered mantle and eroded both soil and unaltered bedrock, contributing a smaller portion of "fresh" igneous and metamorphic minerals to the sediment-laden upland streams.

The development of red upland soils is supported through a consideration of other possible modes of origin of the red pigment within the red lenses of the Willwood. Erosion of older red beds, such as the Triassic Chugwater Formation, could have provided red pigment, but available field evidence shows no discernible relationship between exposures of red beds and the accumulation of variegated deposits (Van Houten, 1948). The continual development of red-banded formations after red beds were stripped from the Laramide uplifts or buried beneath the basin fill suggests that other factors were

responsible for the red pigment.

Two processes are considered for possible development of red pigment at the site of deposition. One was the development of red soil. However, a distinction must be made between a well-drained upland region with intense soil-forming conditions and an aggrading lowland with a shallow water table and relatively continuous deposition (Van Houten, 1948). Under such lowland conditions any soil formed would have been an "alluvial" soil showing little or no modification excepting a slight accumulation of organic matter on the surface (Kellogg, 1941). The other process was for chemical changes under a semi-arid climate to develop a red sediment color (Van Houten, 1948). However, evidence concerning the early Cenozoic environment of the Big Horn Basin does not indicate such a climatic condition, and the process fails to account for the development of both drab and red layers.

Nature of the Depositional Area

The upland areas were drained by numerous streams flowing into the basin lowlands and depositing sediment in channels and on related flood plains. Numerous conglomerate wedges on the basin margins (Van Houten, 1944) indicate that stream gradients decreased rapidly as they entered the lowland areas. Seasonal rainfalls and "cloudbursts" in the upland areas conducive to high and low water periods also contributed to

sharp changes in stream velocities and transporting competence.

Deposition of red-banded Willwood sediments appears to have taken place in a seasonally humid, warm-temperate to subtropical climate (Van Houten, 1948). The basin landscape probably resembled modern-day savannahs, with broad grassy areas interspersed with forested areas bordering streams. Through seasonal flooding and periodic shifting of channel positions, stream sediment derived from red upland soils and bedrock was spread laterally across the basin surface. The oxidized (red) nature of the source material was maintained in the streams due to both the short time interval and distance of transport from source area to site of deposition. Through the sorting action of moving water, coarse sediment accumulated within and along the major stream channels, whereas the finer silt- and clay-sized material containing red pigment was deposited in adjacent alluvial areas.

The Early Eocene covered a time interval of approximately six million years (Funnel, 1964). Assuming 2,500 feet as an average Willwood thickness across the central portion of the basin, the rate of sediment accumulation is calculated at 1 foot in 2,400 years. This figure compares favorably with 1 foot in 3,000 years for the "Wasatch" of southwestern Wyoming (Bradley, 1930). Although these figures are relatively high, deposition of the Willwood was of an intermittent nature, with periods of little or no deposition interrupted by the influx of much

sediment and rapid deposition in stream channels and adjacent alluvial areas.

While red alluvium was transported to the various depositional sites of the Willwood landscape, final sediment color was dependant on local environmental conditions. Forested and swampy areas bordering streams were probably characterized by a water table at or within a few inches of the ground surface. Rapid decomposition of organic material was prohibited, and reducing conditions at the surface of sediment accumulation brought about alteration of ferric iron to ferrous iron and gray sediment colors. The lateral flood plains and inter-stream areas had a deeper water table. Oxidizing conditions at the ground surface destroyed a large portion of organic material, and the oxidized (red) nature of the sediment pigment was preserved. Between these two environments on the Willwood landscape was a transitional area marked by a fluctuating water table and alternating oxidizing and reducing conditions. Partial reduction of the sediment resulted in pale maroon, buff, and mottled strata.

The interfingering relationship of beds within the Willwood Formation demonstrates that the areas of various oxidizing and reducing environments varied laterally with time. As major stream systems shifted, the position of particular depositional environments was correspondingly changed. Previous workers have referred to the lateral migration of Willwood

streams across the basin surface as a meandering process (Van Houten, 1948). The writer, however, believes that meandering of major channels was not a dominant process. Such an opinion is based on the fact that numerous exposures of Willwood strata reveal the presence of distinct and isolated channel bodies eroded into underlying siltstones and claystones. Sandstone units extending laterally from the main channel occur only at the upper portion as thin "sheet" sandstones. If meandering was a common feature of aggrading Willwood streams, the thicker channel portion of the sandstone unit should have extended over a wider, lateral distance, with localized cut-and-fill relationships obliterated.

The lateral migration of Willwood streams was probably an intermittent and relatively sudden process. Due to the actively aggrading nature of the streams, major channels were rapidly filled with coarse detrital material. Stream banks became correspondingly less and less effective in confining a stream to its main channel under normal flow conditions. With continued aggradation the channel became completely filled with sediment and was broken into smaller distributaries spreading laterally over a broad alluvial plain. A "braided" pattern resulted, with normal stream flow occurring in smaller distributaries shifting course so often and swiftly that no new channels were cut. Such a stage in stream development was recorded by the laterally extending, "sheet" sandstones. With continued aggradation of sand a "choking-off" point was

reached, where the landscape was no longer able to control the stream position. At such a time a given flood stage resulted in the establishment of a new and more stable stream channel significantly removed from the original stream position to a lower portion of the landscape. By receiving the major portion of stream flow, the stream eroded into underlying sediments and established a new channel. The former stream system soon became dry and gradually changed in accordance with its new environment.

The general process of lateral stream migration during Willwood times appears similar to conditions of sedimentation on alluvial fans. Blissenbach (1954, p. 178), in discussing alluvial fans at the base of the Santa Catalina Mountains in southern Arizona, reported:

Thus, fan channels frequently are silted up causing overflows and forming new distributaries. When one sector of a fan has been built up, the streams shifted to another, lower section of the fan and built that up. The process is repeated again and again until the mountain stream and the alluvial fan have reached graded conditions.

Hewett (1926) reported on the presence of a large, triangular-shaped, alluvial fan in the southwestern portion of the present Big Horn Basin. Its apex appeared to be located at the point of emergence of a major river supplying Willwood sediments to an extensive alluvial plain.

Stratigraphic observations show that most channels were cut into red and maroon sediments, indicating that newly

established channels were removed from the previous stream and bordering vegetated areas characterized by reduced sediment colors. The presence of red beds conformably overlying sandstone units indicates that the former stream bed was followed by an oxidizing depositional environment associated with sparsely vegetated, interstream areas.

It was previously stated that the poorly drained, basin lowlands were not favorable for strong soil development. Evidence exists, however, within the study area for strata representing soils with a definite profile. In particular, the lavender-colored siltstones and claystones, discussed previously as key or marker beds, contain the following characteristics that appear related to paleosols.

1. Lavender-colored strata commonly occur at the top of a red or maroon bed of similar lithology. Such a relationship may represent incorporation of organic matter within the upper portion of a particular red bed in an amount higher than usual. Although oxidizing conditions were present, partial reduction of the sediment was achieved and the lavender color represents an incipient A horizon of a developing soil profile.
2. The lateral persistence of certain lavender beds, such as "Bed A" of Rohrer and Gazin (1965), occurs at a scale much greater than that of other Willwood strata, and appears to represent soil development over

a wide area.

3. A lavender-colored claystone bed was observed that appeared to have a discordant relationship with underlying beds and follow a paleotopography. Such a relationship is characteristic of paleosols, demonstrating the development of a unit upon the landscape subsequent to deposition.
4. An overlap, a few feet thick, of the Gray Bull and Lysite Faunal Zones occurs within "Bed A" (Rohrer and Gazin, 1965). Such a relationship may be related to an extended period of greatly reduced sediment accumulation. Soil development occurred, and the contained fossil material reflected the significant change in fauna taking place during the extended time interval of "nondeposition".

Development of a soil over a large portion of the landscape implies conditions of sediment accumulation somewhat different than those normally associated with the Willwood Formation. Periodic fluctuation of climate is a possibility, with dryer conditions having drastically reduced deposition in the basin and allowed for the development of a soil profile. Such a change, however, would presumably have affected a large area, including upland source areas of the Big Horn Basin and possibly other areas of the Cordillera. The sedimentary record of the region provides no evidence for such climatic

changes (Van Houten, 1948), and the development of Willwood soils appears to be dependant on other factors restricted to the basin area.

Since a decrease in the normally high rate of sediment accumulation appears as a necessary factor for the formation of soils, the writer is of the opinion that changes in the nature of the source area may have caused soil development in the lowlands. The rate of sediment accumulation during Willwood times was controlled by the rate of erosion of the surrounding, uplifted source areas and basin subsidence. Fluctuations of the orogenic movement could have, at times, allowed stream erosion to significantly reduce the elevation difference between the upland areas and the aggrading basin surface. The reduced elevation resulted in a decrease in the amount of material eroded and supplied to the basin area. Surficial material across the Willwood landscape was not as rapidly buried and, therefore, it was subjected to a much longer period of weathering. Time was available for the translocation of materials in solution and suspension, with concentration of mineral matter at particular levels. A greater amount of organic matter accumulated in the surficial material, and a discernable soil horizon developed. Subsequent uplift in the upland source areas rejuvenated stream erosion, and the rate of sediment accumulation increased to its normal level, prohibiting further soil development.

The writer wishes to point out that, although many of the lavender-colored units of the Willwood display characteristics associated with preserved soil profiles, conclusive evidence is not available. The hypothesis is presented as a possible explanation accounting for the particular features contained by these units and more detailed study in the field and laboratory is necessary to definitely establish whether such units are paleosols.

The environment of the Early Eocene Big Horn Basin recorded in Willwood sediments is significant for the development of red beds. During Paleocene times sediment received from the surrounding upland regions was deposited in predominately a humid, heavily vegetated basin lowland characterized by widespread sediment-reducing conditions and the complete alteration of red sediment to grayish-green and other drab colors. During the Early Eocene a seasonally humid, savannah environment with widespread fluctuation of forest and sparsely-vegetated areas permitted both oxidizing and reducing conditions and the preservation of a portion of the red pigment delivered to the depositional site. In general, it appears that the red-banded Willwood Formation represents an environment transitional between the heavily forested lowlands of early Cenozoic time and widespread grasslands of medial and late Cenozoic (Van Houten, 1948).

CONCLUSIONS

Through an analysis of lithologic and stratigraphic features of the Willwood Formation the writer has concluded that:

1. Particular stratigraphic relationships are repeated in a sequence of strata, indicating a "repetative" nature to the mechanism of sediment deposition.
2. Certain sandstone and lavender-colored strata display characteristics favorable for their use as key beds for stratigraphic correlation.
3. Lithologic, stratigraphic, and faunal relationships indicate that the Willwood Formation accumulated in a lowland, savannah-like environment. Sediment derived from red soils and unweathered bedrock in surrounding upland areas was transported by streams onto a generally flat, basin surface. Coarse material was deposited within and along stream channels, while finer sediment accumulated on adjacent alluvial areas.
4. Lateral migration of streams was a relatively rapid process, with channels filled with clastic material until a "choking-off point" was reached, and stream flow was diverted into a new area.
5. Particular lavender-colored, siltstone-claystone beds exhibit characteristics related to preserved soil profiles.

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